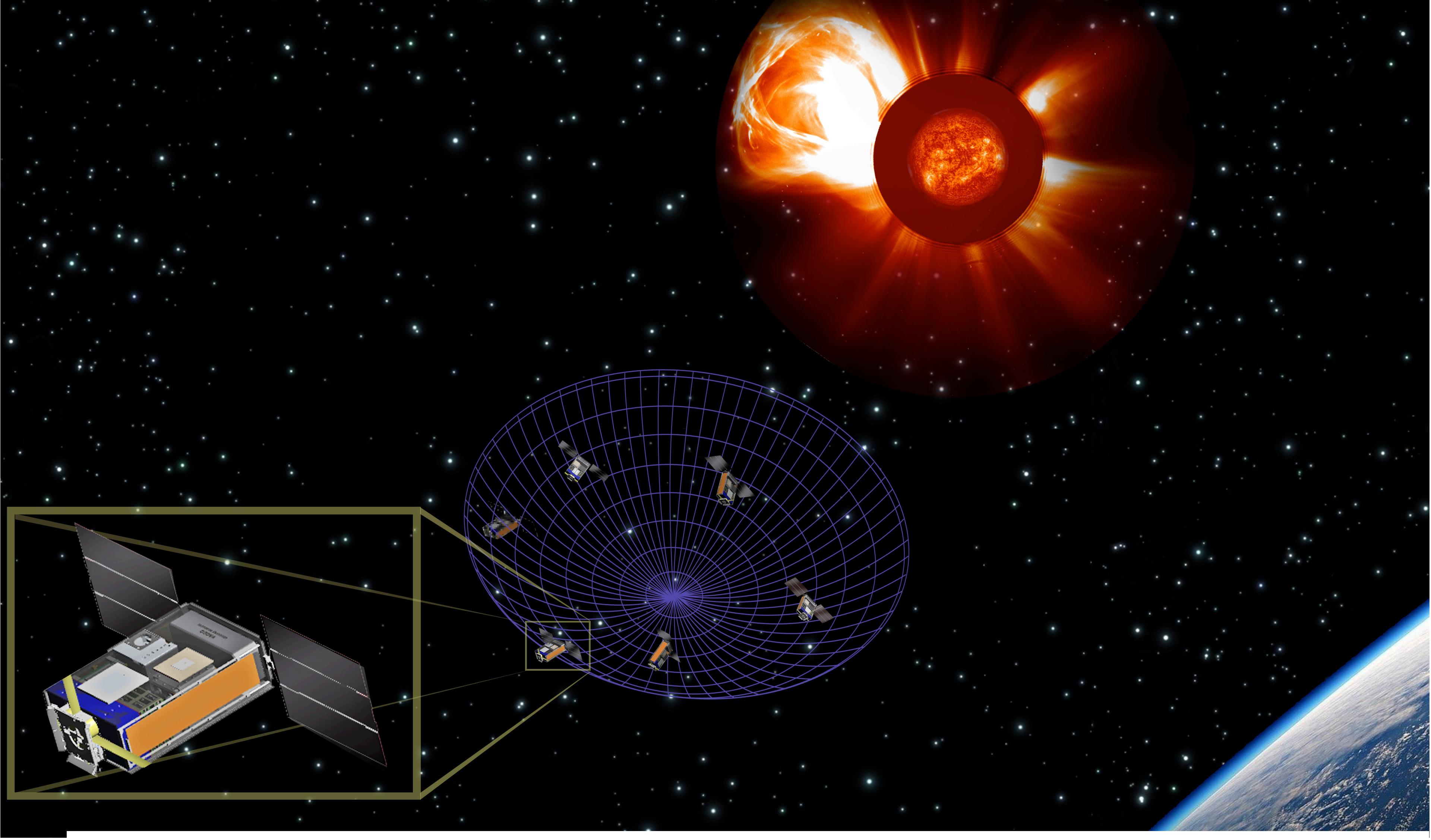


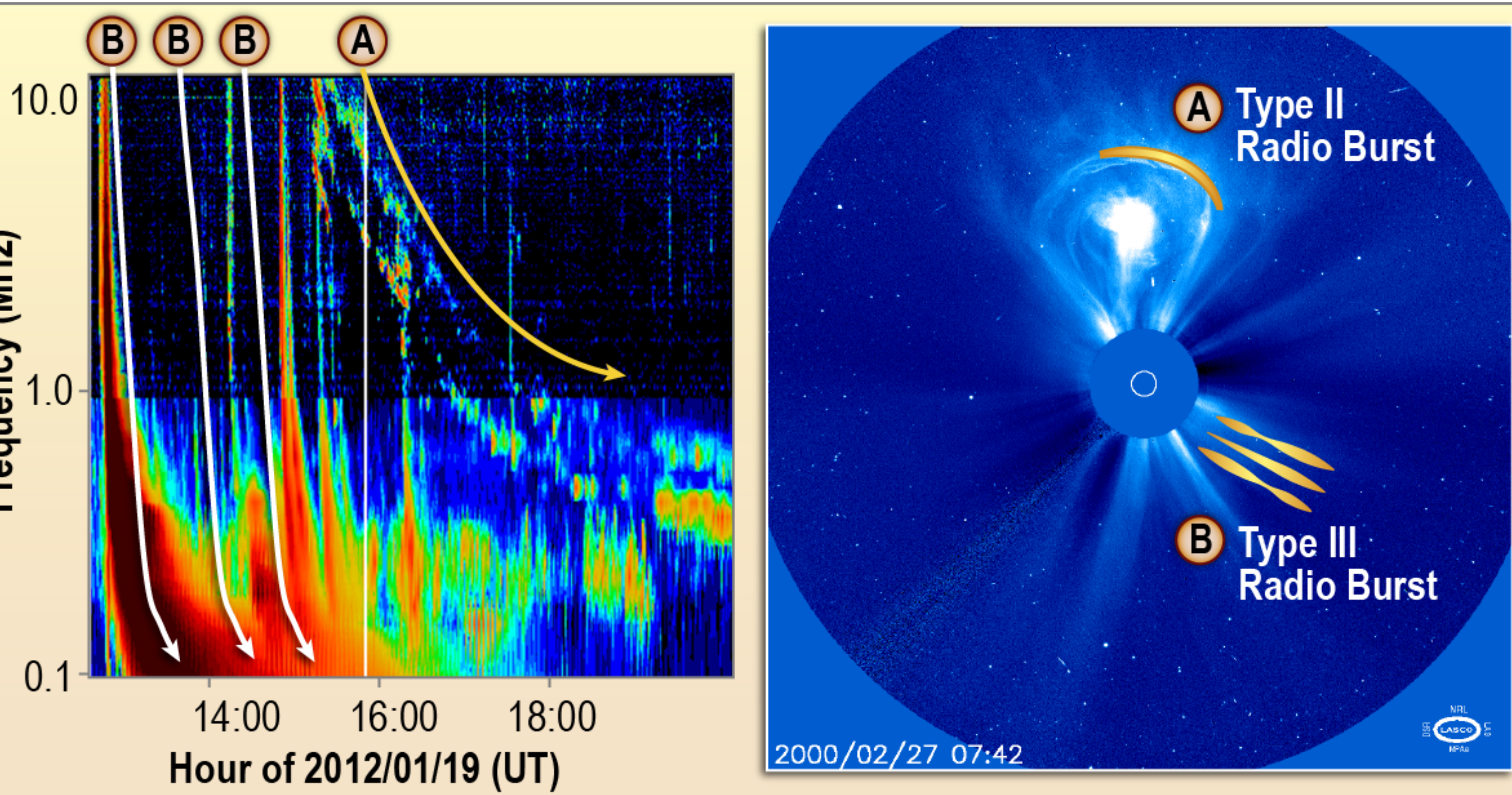
Sun Radio Interferometer Space Experiment (SunRISE)

Joseph Lazio, Justin Kasper, SunRISE Team

Jet Propulsion Laboratory
California Institute of Technology

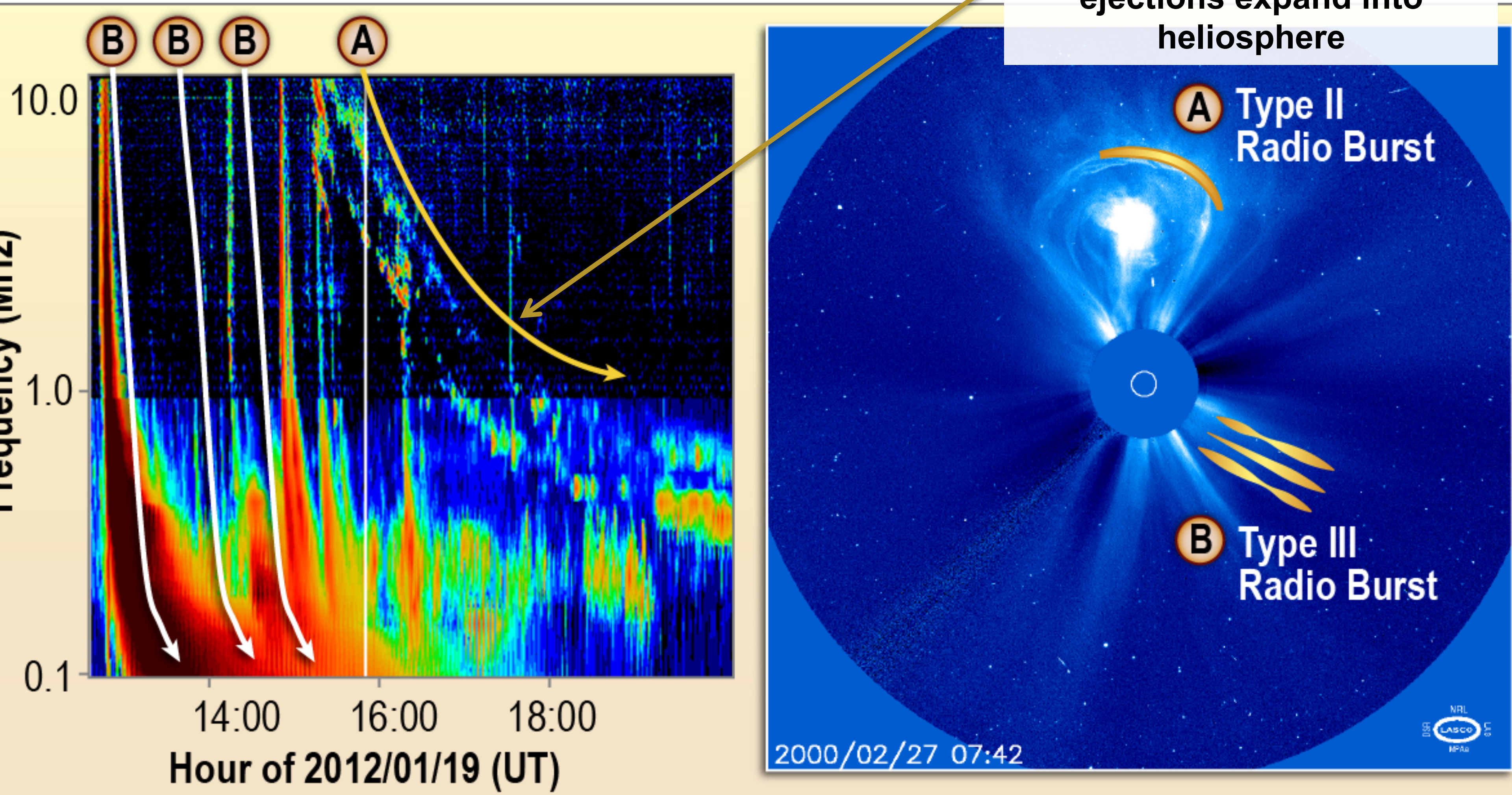
Solar Radio Bursts

Type II and III



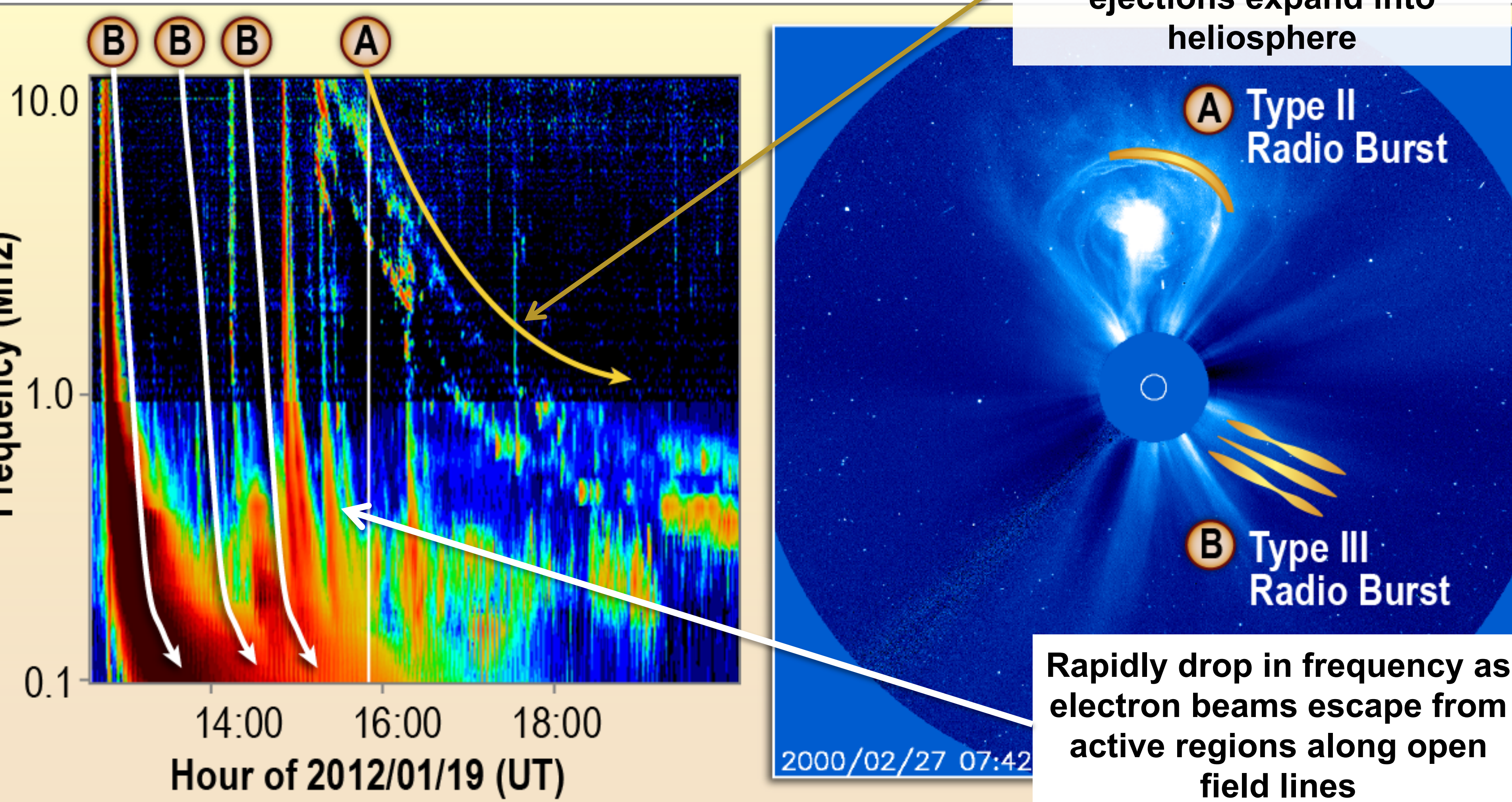
Solar Radio Bursts

Type II and III



Solar Radio Bursts

Type II and III

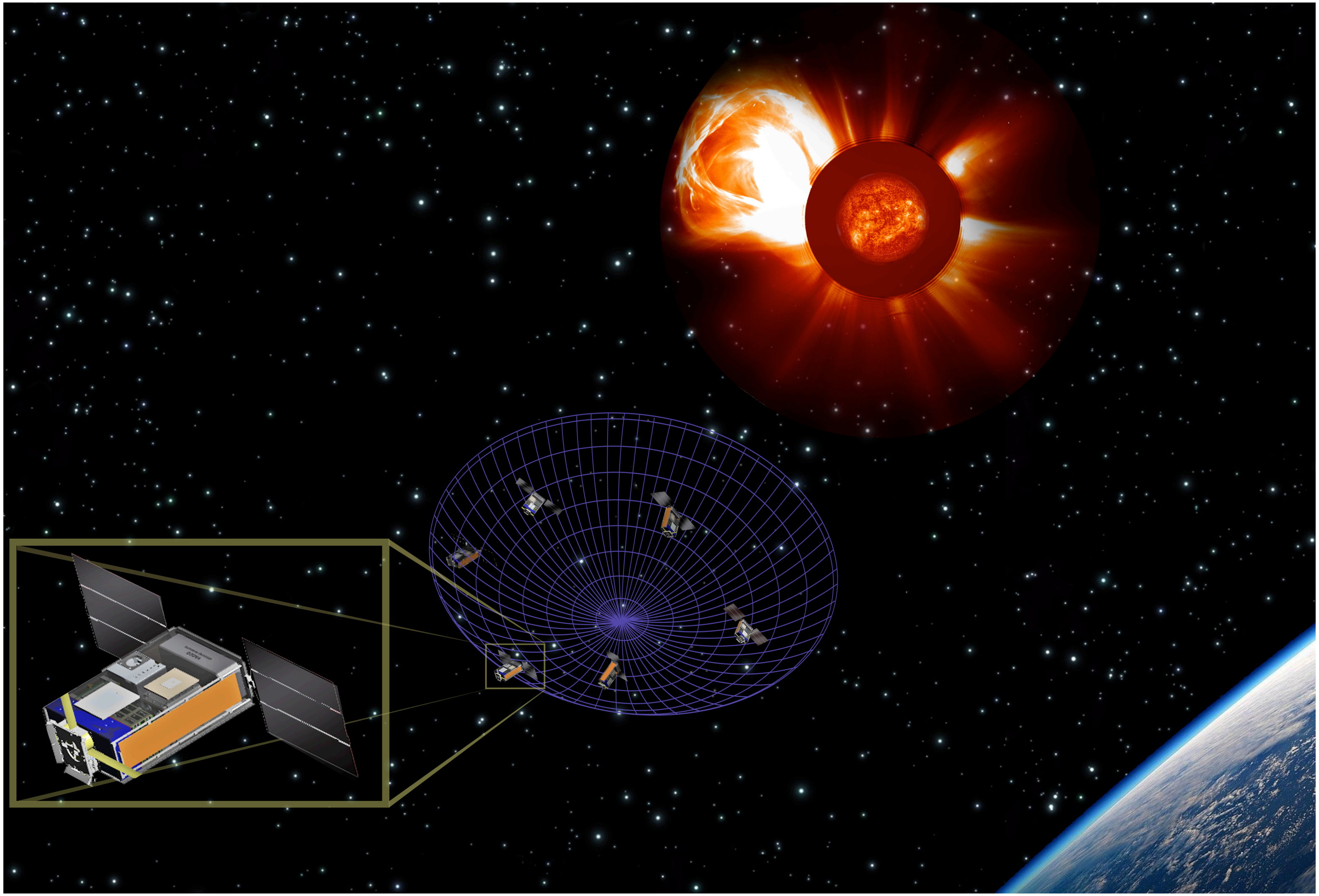


Slowly descending in frequency as coronal mass ejections expand into heliosphere

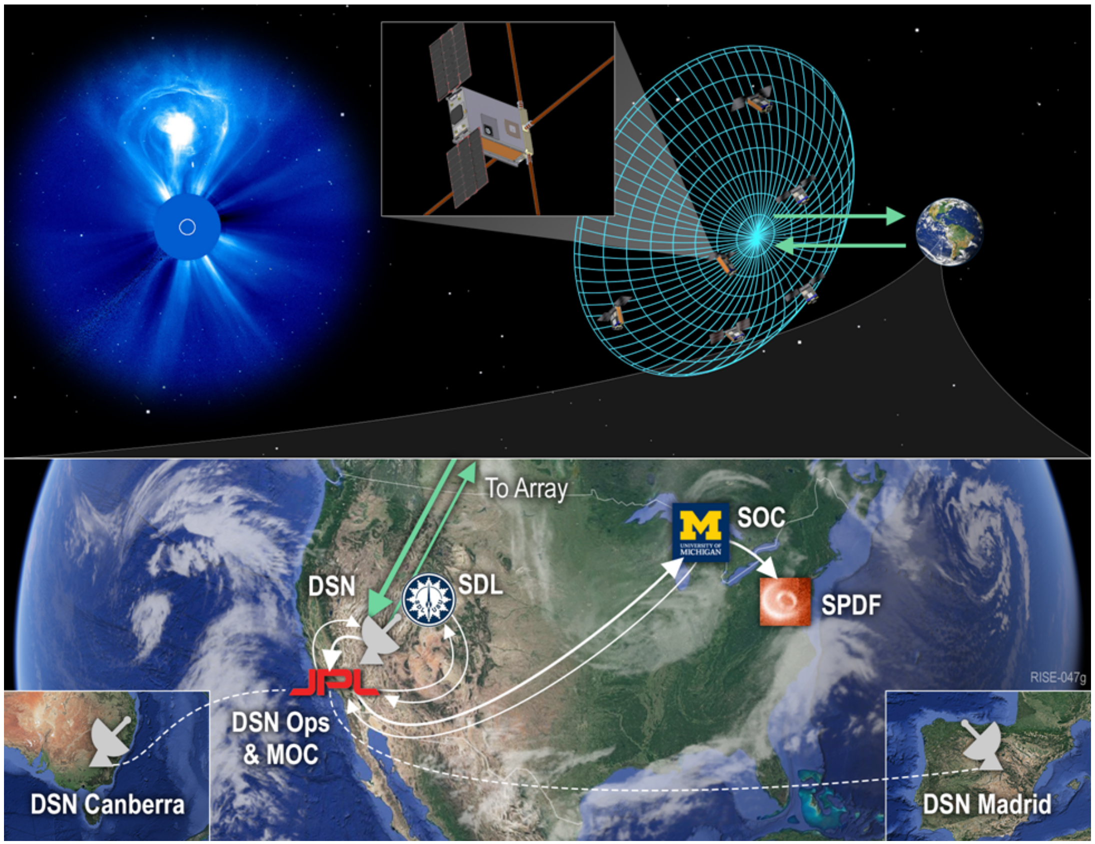
Rapidly drop in frequency as electron beams escape from active regions along open field lines

Science Implementation Concept

Synthetic Aperture!



Science Implementation

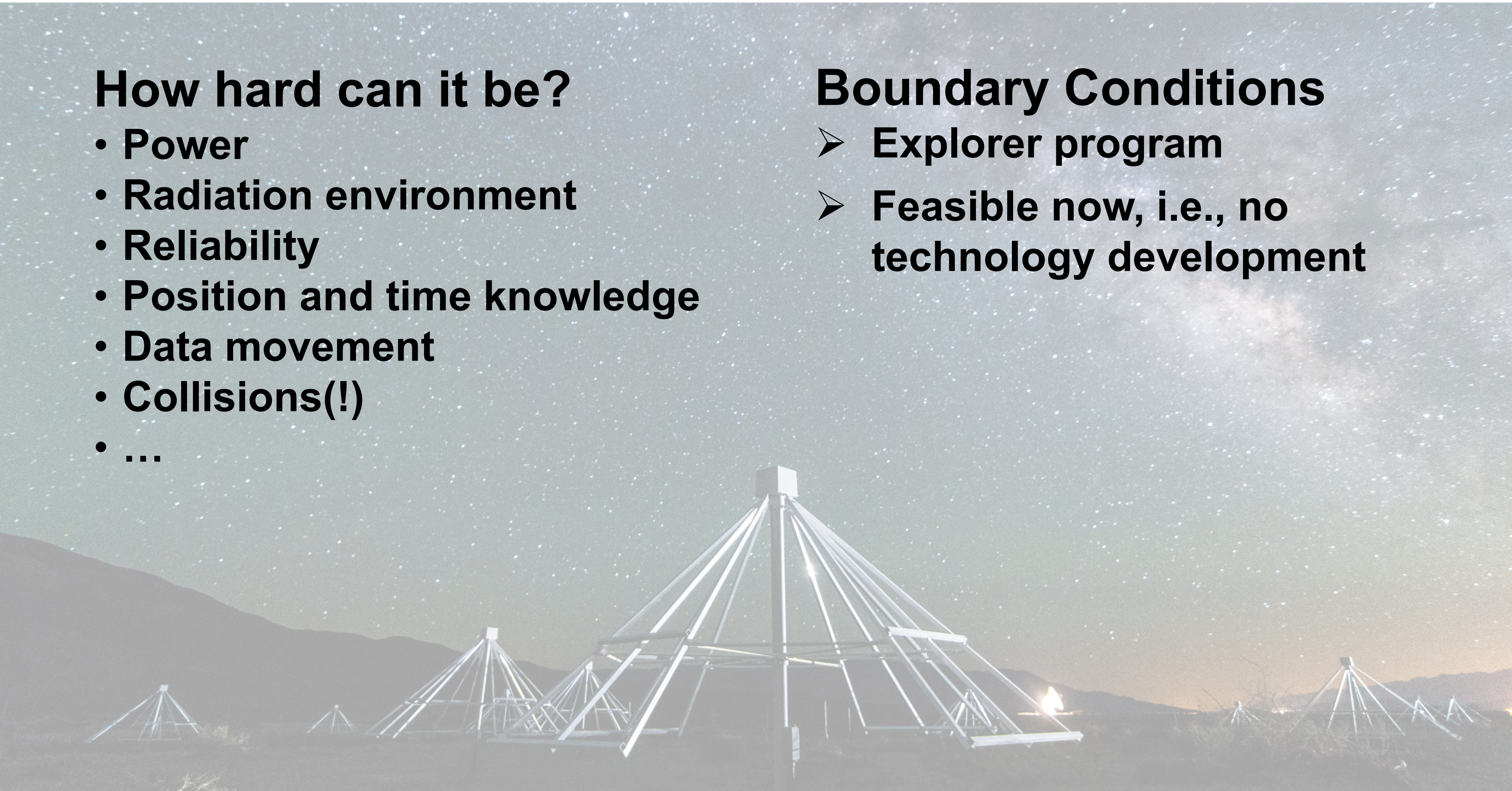


- **First interferometer in space, first decametric-hectometric (DH) imaging**
- **Loose formation of six 6U form factor CubeSats in ~ 10 km sphere**
- **GEO+ Orbit (25 hr orbit period)**
- **DH radio receiver (0.1 MHz – 20 MHz) with crossed 5 m dipole antennas**
- **Data collection in 0.655 ms bursts every 100 ms, select from 4096 frequencies**
- **Relative position knowledge to within 3 m and timing to ns**
- **Direct delivery to GEO+ as secondary payload**
- **3 GB of data per week, all downloaded no bursts or triggers**
- **2022 March Launch Readiness, six month Phase E**

Space-based Radio Interferometer

Lift Long Wavelength Array-Owens Valley (or LWA1 or LOFAR or RAPID or …) into space.

Space-based Radio Interferometer



How hard can it be?

- Power
- Radiation environment
- Reliability
- Position and time knowledge
- Data movement
- Collisions(!)
- …

Boundary Conditions

- Explorer program
- Feasible now, i.e., no technology development

Space-based Radio Interferometer

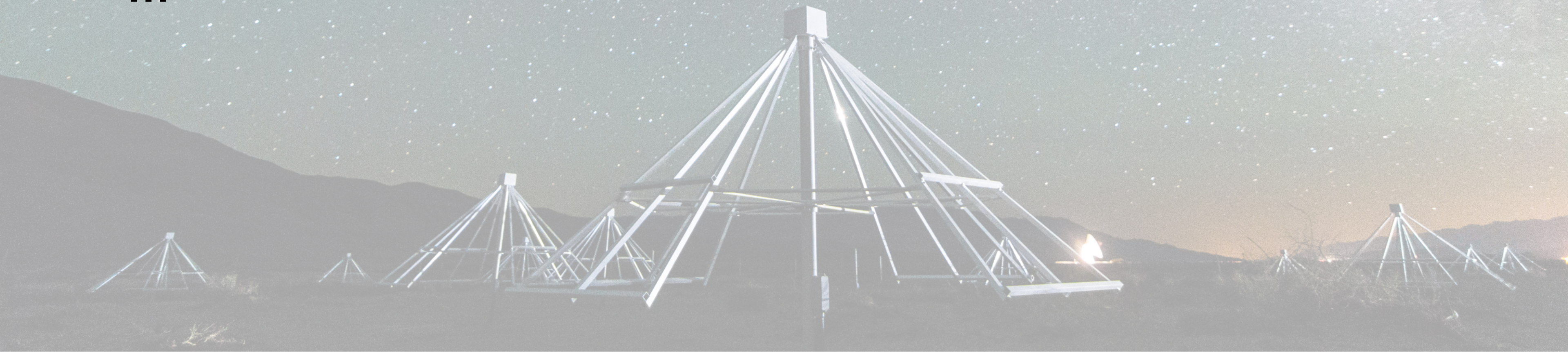
How hard can it be?

mass

- Power
- Radiation environment
- Reliability
- Position and time knowledge
- Data movement
- Collisions(!)
- …

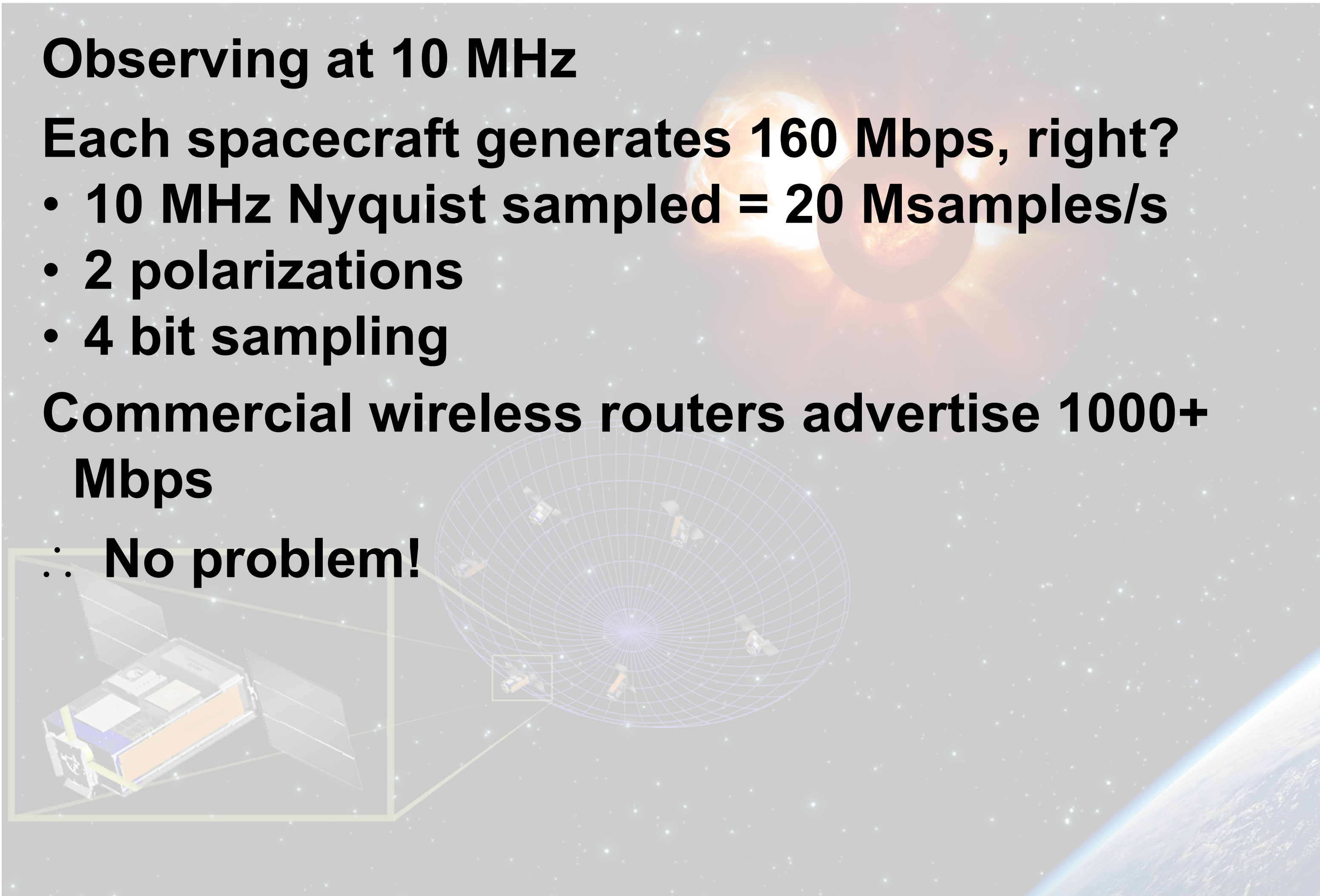
Boundary Conditions

- Explorer program
- Feasible now, i.e., no technology development



Data Movement

Science Implementation Challenge



Observing at 10 MHz

Each spacecraft generates 160 Mbps, right?

- **10 MHz Nyquist sampled = 20 Msamples/s**
- **2 polarizations**
- **4 bit sampling**

Commercial wireless routers advertise 1000+ Mbps

∴ No problem!

Data Movement

Science Implementation Challenge

Observing at 10 MHz

Each spacecraft generates 160 Mbps, right?

- **10 MHz Nyquist sampled = 20 Msamples/s**
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- **4 bit sampling**

Commercial wireless routers advertise 1000+ Mbps

∴ No problem!

Problem: spectrum allocations limit SunRISE to 2 Mbps

Solution: Reduce total bandwidth

Solution: Use DSN multi-spacecraft per aperture

Solution: Correlation done on ground

Correlation

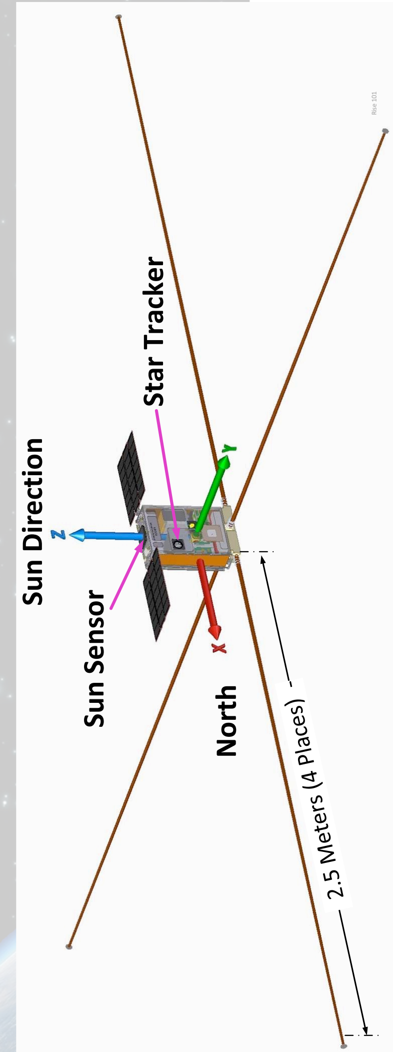
Science Implementation Challenge

- **Position and time knowledge of spacecraft required**
  - **Sub-meter knowledge**
- **Problem: 3 radios? Science, telecommunications, ranging**
  - **Mass, power, …**
- **Problem: Real-time orbit determination?**
- **Solution: Use FX Correlator architecture coupled with GPS timing, dump spectra to ground, subsequent ground-based precise orbit determination and correlation**

Collisions

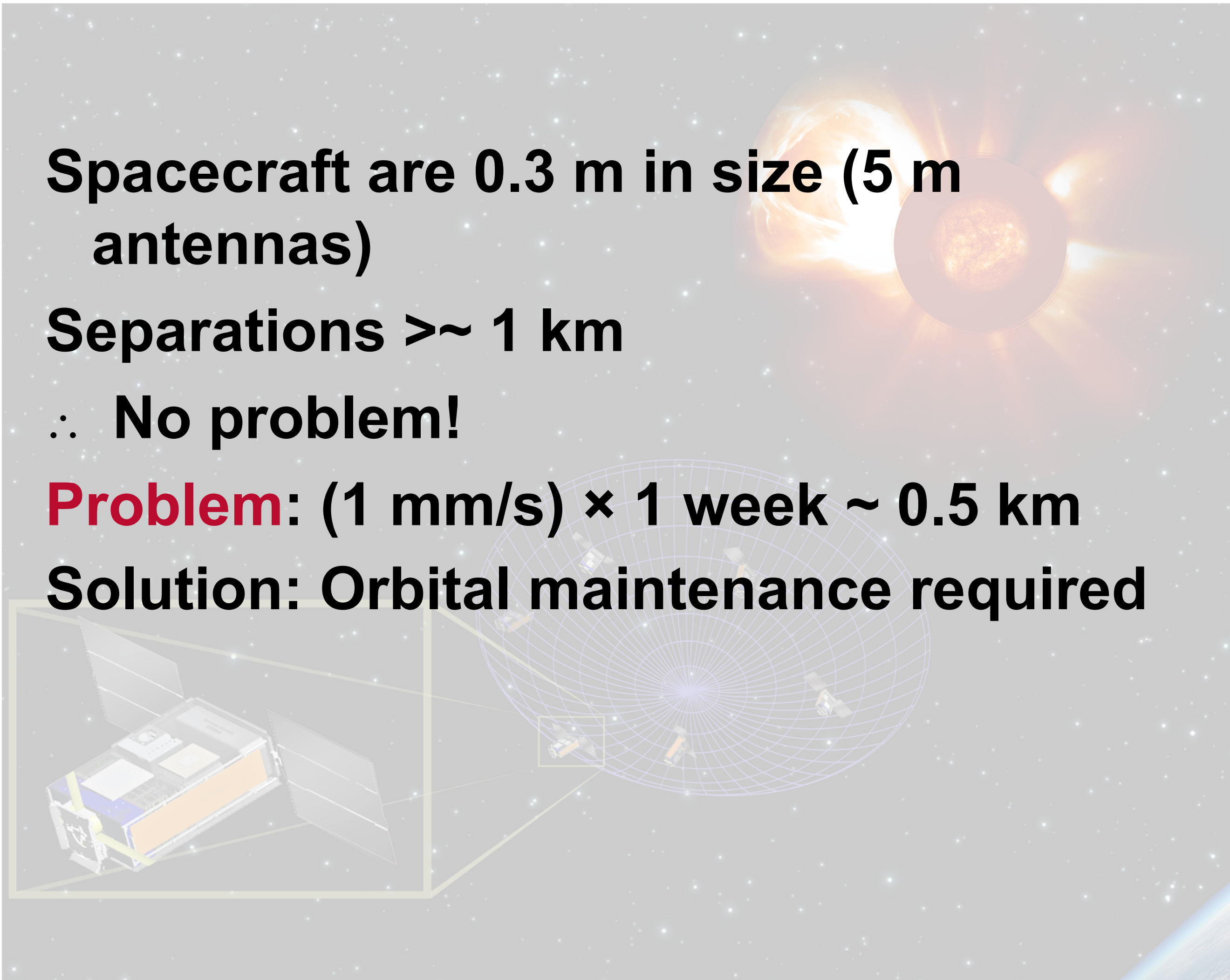
Science Implementation Challenge

- Spacecraft are 0.3 m in size (5 m antennas)
- Separations >~ 1 km
- ∴ No problem!



Collisions

Science Implementation Challenge



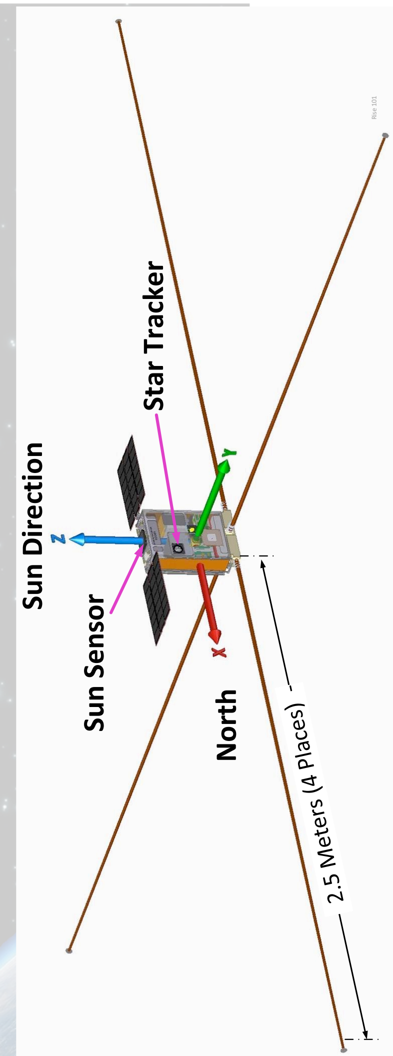
Spacecraft are 0.3 m in size (5 m antennas)

Separations >~ 1 km

∴ No problem!

Problem: (1 mm/s) × 1 week ~ 0.5 km

Solution: Orbital maintenance required



Space-based Low Radio Frequency Arrays

Astron. Astrophys. 195, 372–379 (1988)

ASTRONOMY AND ASTROPHYSICS

A low frequency radio array for space

K.W. Weiler[1], B.K. Dennison[1,2], K.J. Johnston[1], R.S. Simon[1], W.C. Erickson[3], M.L. Kaiser[4], H.V. Cane[4], M.D. Desch[4], and L.M. Hammarstrom[1]

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[2] Virginia Polytechnic Institute and State University, Department of Physics, Blacksburg, VA 24061, USA
[3] University of Maryland, Astronomy Program, College Park, MD 20742, USA
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Received August 4, accepted October 19, 1987

Summary. At the lowest radio frequencies (<30 MHz), the Earth's ionosphere transmits poorly or not at all. This relatively unexplored region of the electromagnetic spectrum is thus an area where high resolution, high sensitivity observations from space can open a new window for astronomical investigations. An array of free flying spacecraft which work as a coherent interferometer will be able to probe this frequency range. Operating from ~1 to ~30 MHz, such a telescope will extend astronomy from just above the ionospheric cutoff, where ground based observations can still be done, down to the fundamental physical limit where observations at still lower frequencies from within the Milky Way are impossible due to absorption by diffuse, ionized interstellar hydrogen.

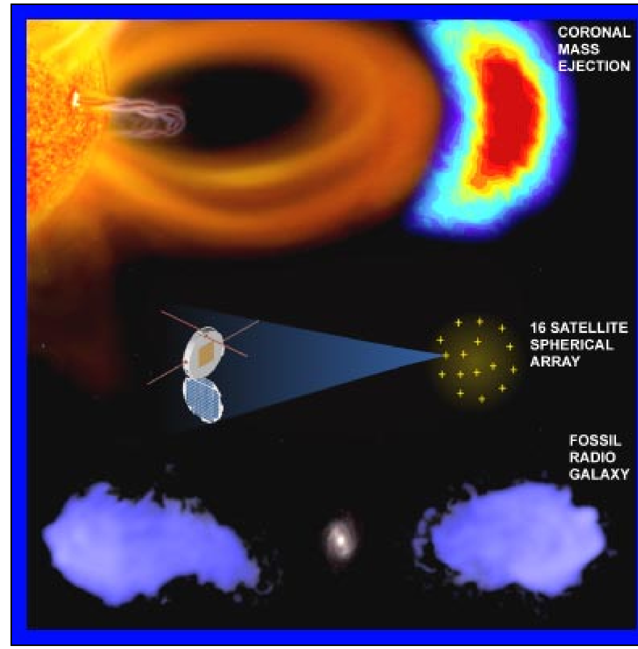
telescopes. Only a few dedicated workers have continued to study the dekameter-hectometer wavelength radiation.

The most extensive investigations at the very lowest frequencies have been carried out with the Radio Astronomy Explorer (RAE) satellites 1 and 2 (Weber, Alexander, and Stone, 1971; Alexander and Novaco, 1974) in Earth and lunar orbit, respectively. They were launched at different dates and used as single survey antennas with their travelling wave V-antennas yielding only steradian resolution. Ground-based observations are normally confined to frequencies >10 MHz during solar minimum or >20 MHz during solar maximum, and only under special conditions at preferred locations does the ionosphere transmit radiation at frequencies as low as 2 to 5 MHz (Reber, 1968; Ellis

The scientific rewards of such a space mission are likely to be great. … a low frequency telescope in space can … study the impulsive low frequency emission from Jupiter and the Sun ….

The Astronomical Low Frequency Array

Viewing the Sun and Universe in a New Light



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Sun Radio Interferometer Space Experiment

Space-based Radio Interferometer

Dawn of space-based arrays

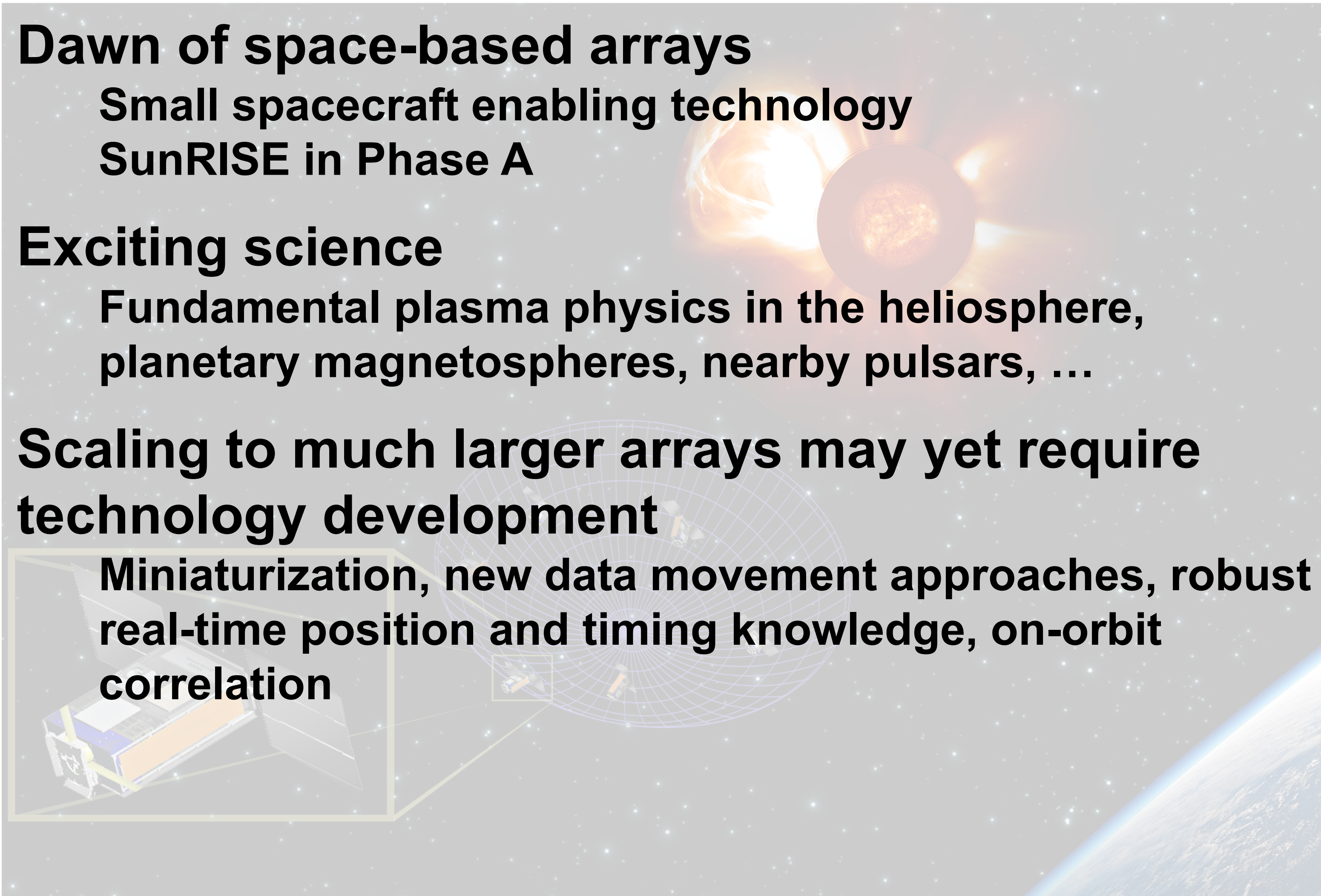
- Small spacecraft enabling technology
- SunRISE in Phase A

Exciting science

- Fundamental plasma physics in the heliosphere, planetary magnetospheres, nearby pulsars, …

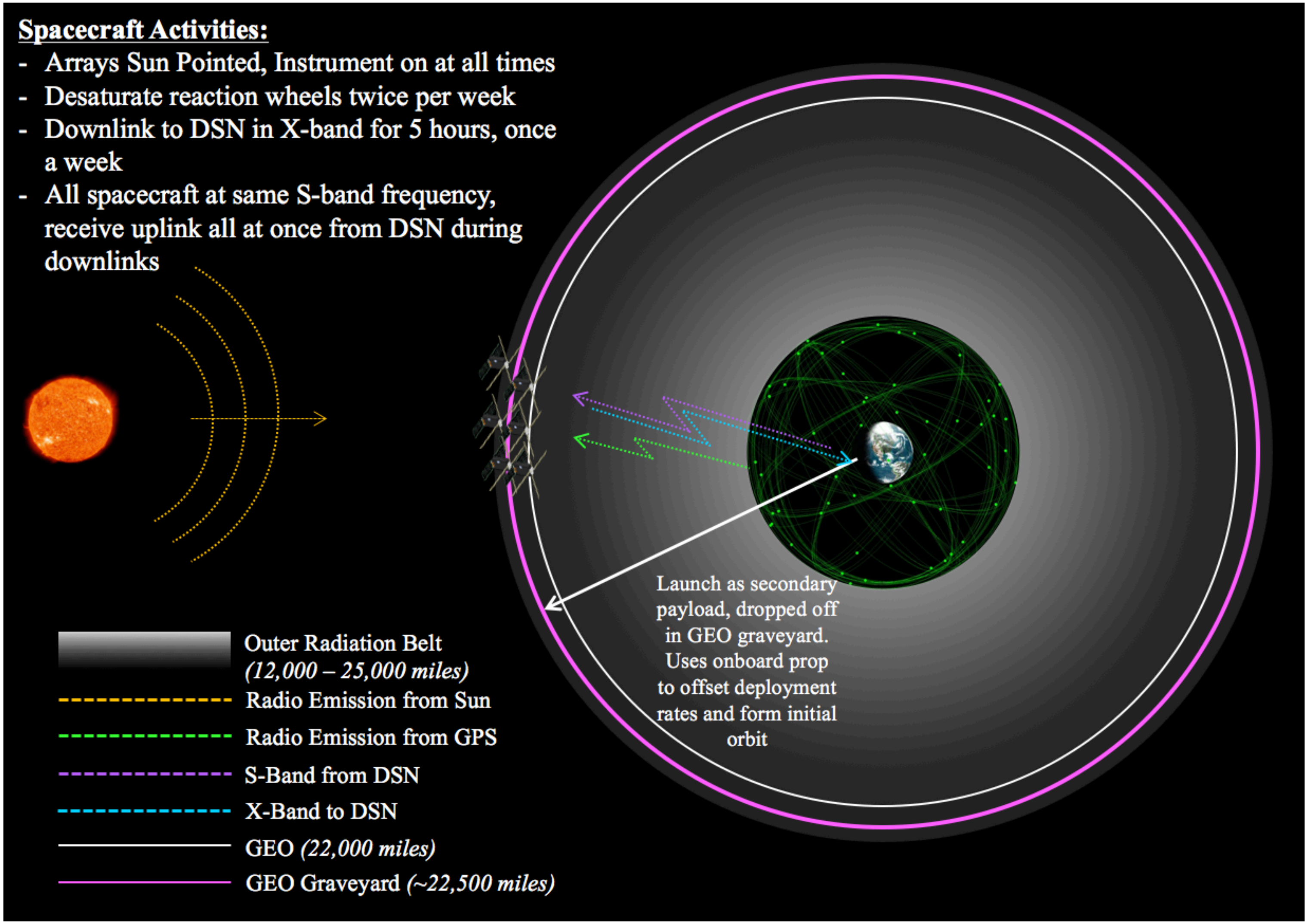
Scaling to much larger arrays may yet require technology development

- Miniaturization, new data movement approaches, robust real-time position and timing knowledge, on-orbit correlation



backup

Concept of Operations



Solar and Space Physics

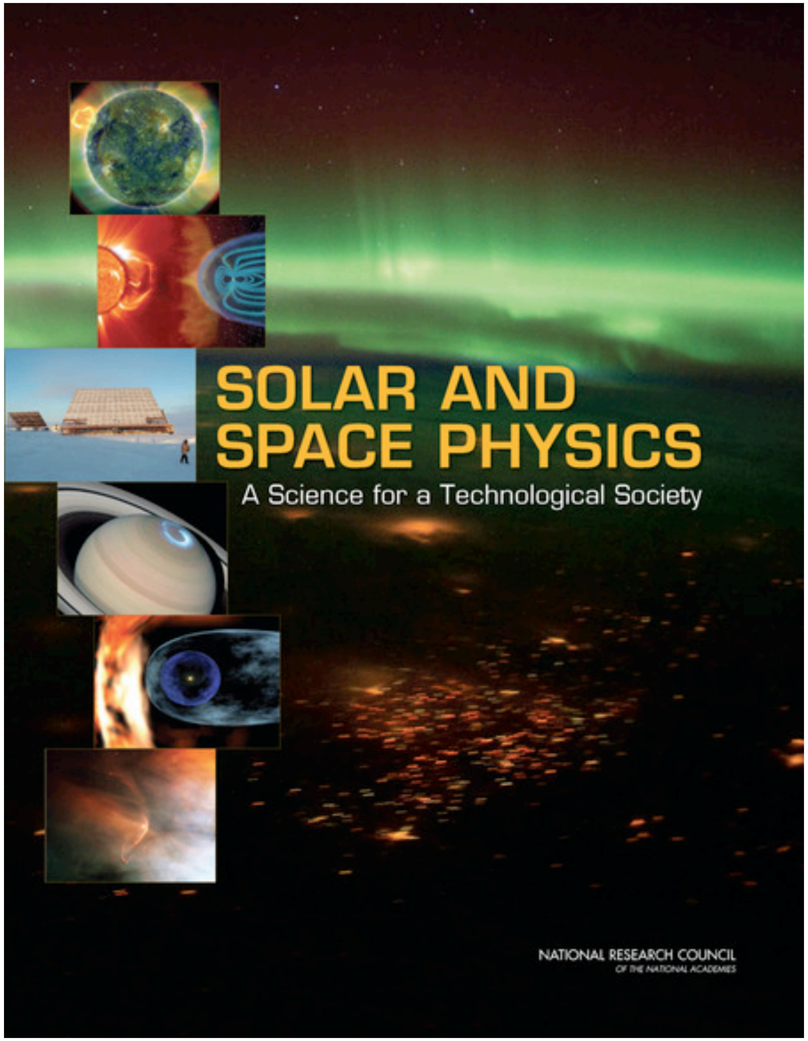
Goal 1. Determine the origins of the Sun's activity and predict the variations in the space environment.

Goal 2. Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere … .

Goal 3. Determine the interaction of the Sun with the solar system and the interstellar medium.

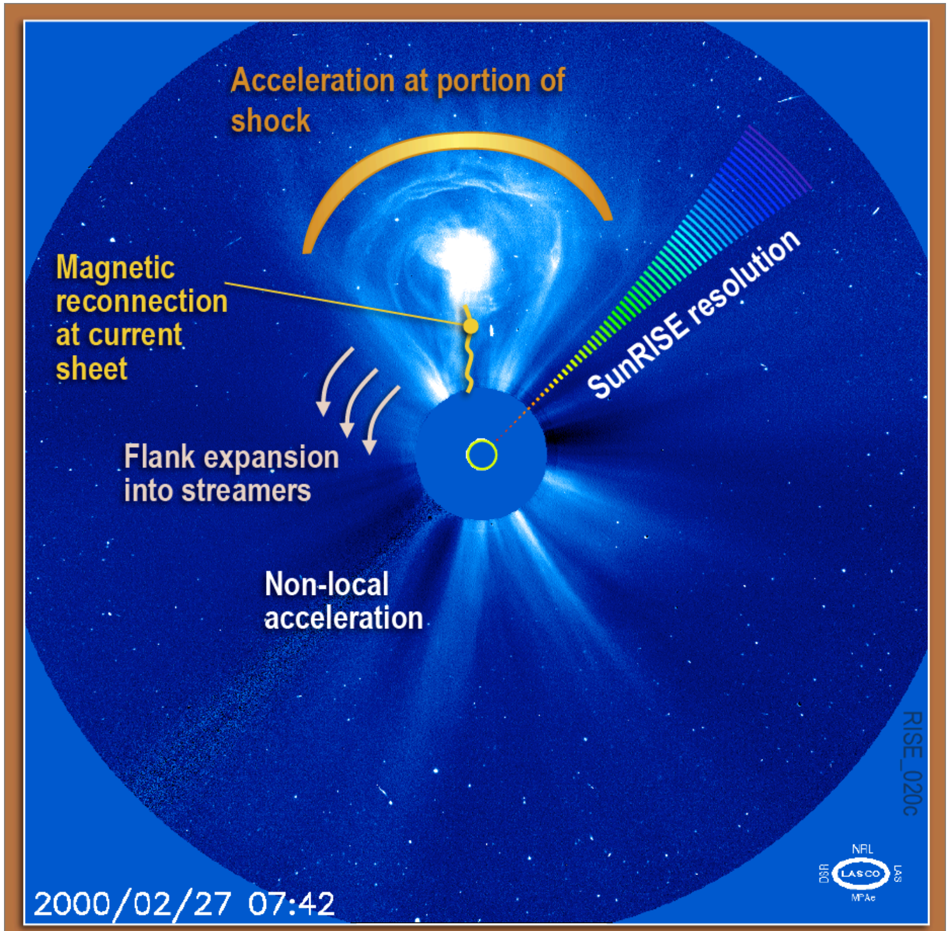
Goal 4. Discover and characterize fun-damental processes that occur both within the heliosphere and throughout the universe.

SHP Panel Goal 3. Determine how magnetic energy is stored and explosively released.



SunRISE Objective #1

The Acceleration of Solar Energetic Particles

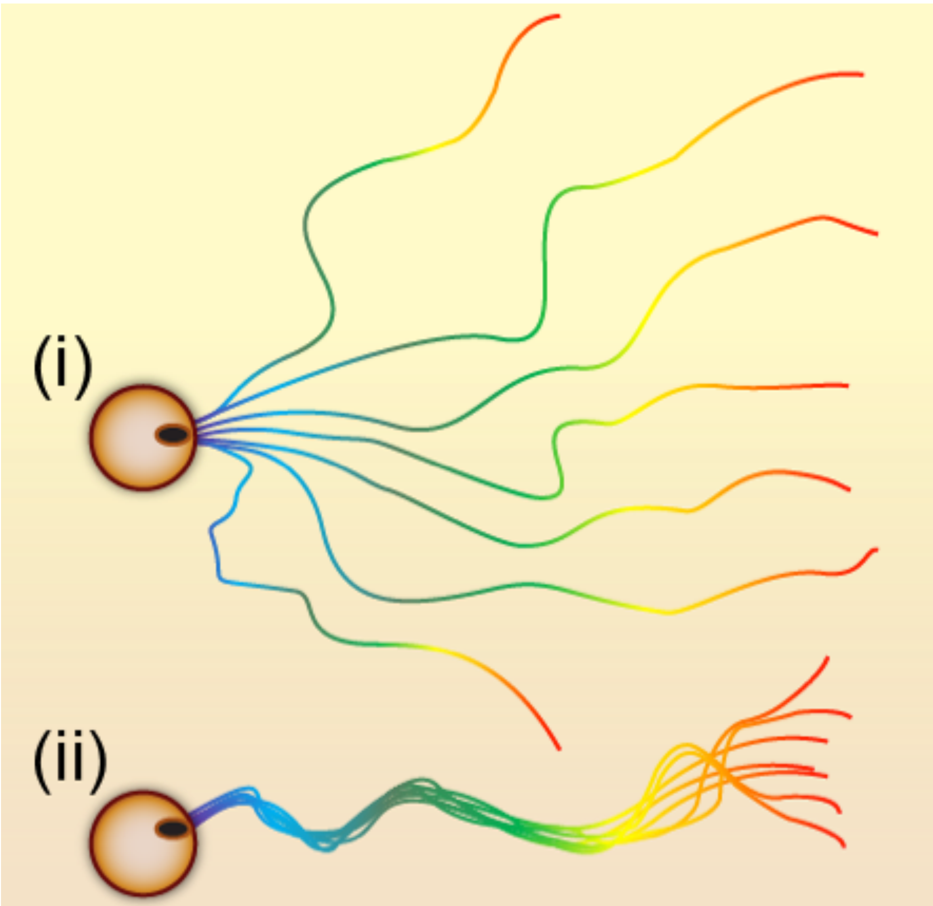


Discriminate competing hypotheses for the generation of solar energetic particles by measuring the location and morphology of associated Type II radio emissions.

- **Major solar energetic particle events proceeded (95% of time) by Type II radio burst below 15 MHz**

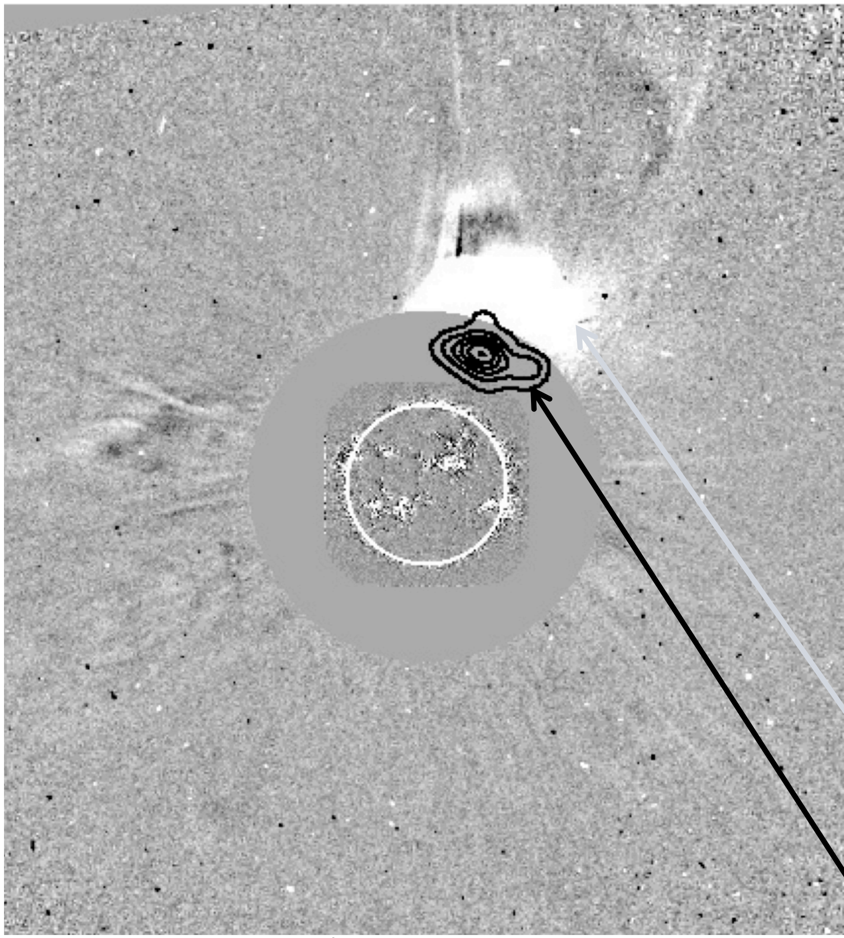
SunRISE Objective #2

The Release of Solar Energetic Particles into Space



Discriminate competing hypotheses for the variable magnetic connection between active regions and the inner heliosphere by reconstructing magnetic field lines associated with Type III radio bursts.

CME Evolution and Particle Acceleration



SDO-AIA 193 Å and SOHO-LASCO C2 images

Ground-based measurements limited to r ~ 2 $R_\odot$

- **Limited frequency range cannot track evolution, limits extent to which radio-optical images can be aligned /correlated**

CME (white light)

80 MHz Gauribidanur image

(Hariharan et al. 2014)

Science Implementation

6 6U spacecraft

Observing 0.1 MHz—25 MHz

Located in supersynchronous GEO orbit (a.k.a. GEO graveyard)

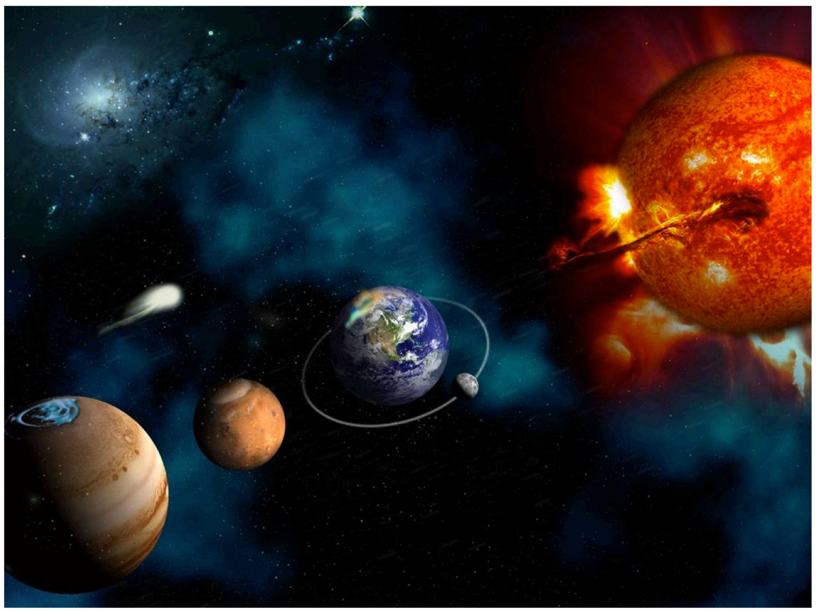
Observing solar Type II and Type III bursts

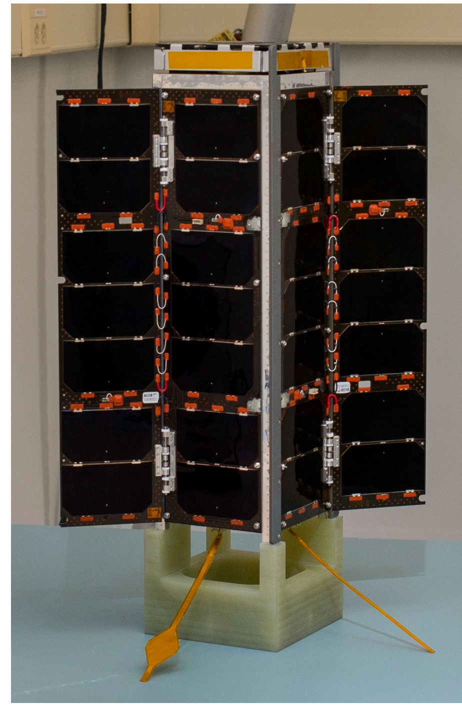
NASA/Heliophysics Announcement of Opportunity	c. 2016 July 20
SunRISE proposal submitted (NASA/Heliophysics SALMON-2 PEA Q/MOO SCM)	2016 October 14
SunRISE selected	2017 July 28
SunRISE Concept Study Report due	2018 July 30
Launch	*c. 2022 July*

Breaking News!

July 28, 2017
RELEASE 17-064

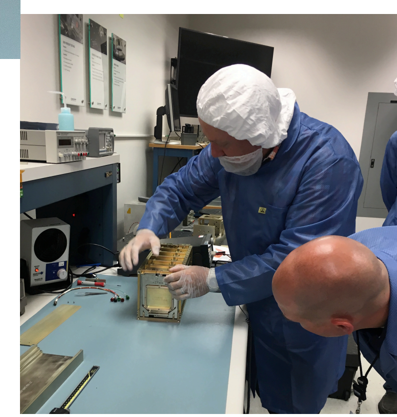
NASA Selects Proposals to Study Sun, Space Environment





DHFR

Launch August 25!



SunRISE

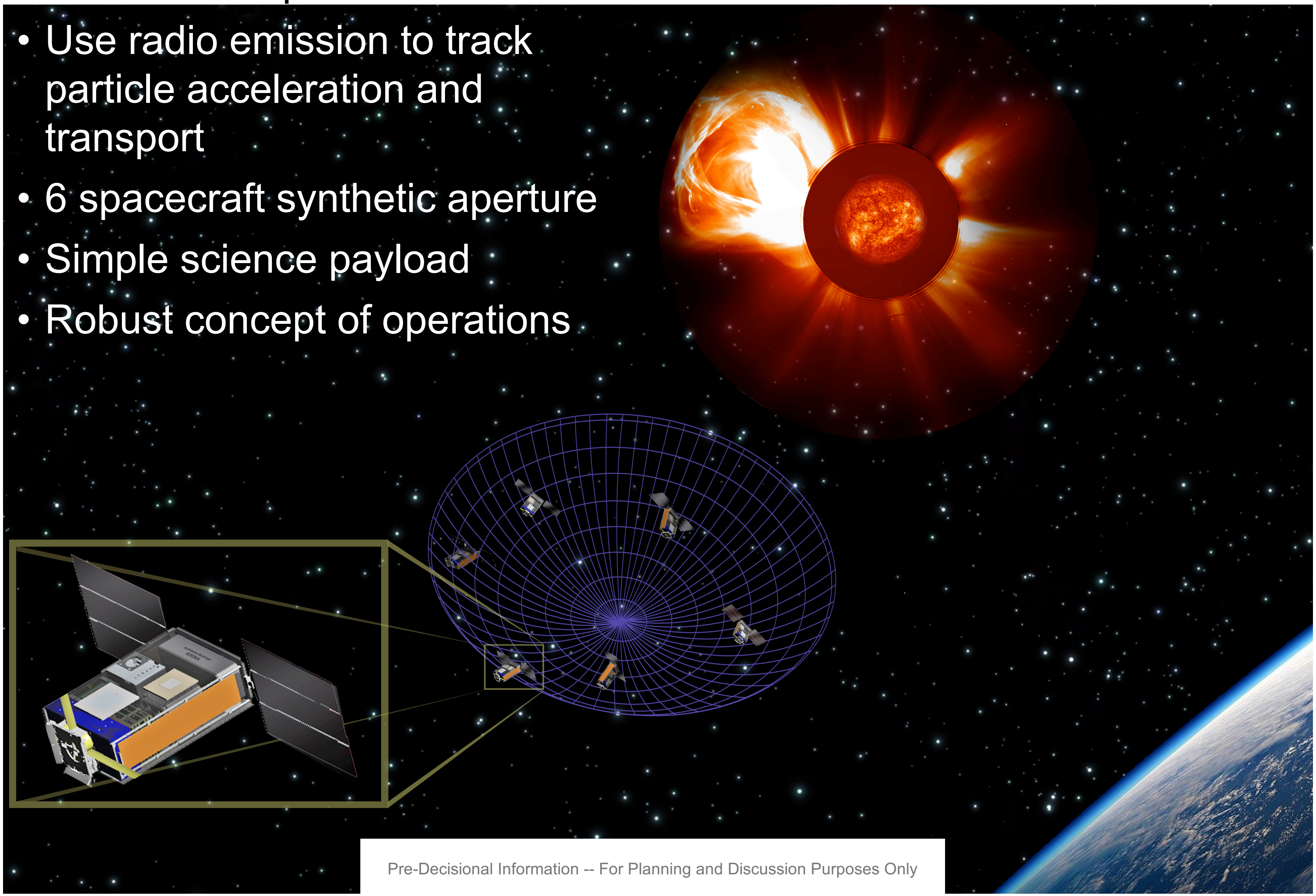
Schedule

NASA/Heliophysics Announcement of Opportunity	**c. 2016 July 20**
SunRISE proposal submitted (NASA/Heliophysics SALMON-2 PEA Q/MOO SCM)	**2016 October 14**
SunRISE selected	**2017 July 28**
SunRISE Step 2 proposal submitted	***c. 2018 July***
Launch	***c. 2022 July***

Sun Radio Imaging Space Experiment

Mission Concept

- Use radio emission to track particle acceleration and transport
- 6 spacecraft synthetic aperture
- Simple science payload
- Robust concept of operations



Position Determination